X-692-70-460
PREPRINT

NASA TM X- 65411

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N. F. NESS
L. F. BURLAGA
K. W. OGILVIE
J. W. SARI

DECEMBER 1970

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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N. F. Ness
L. F. Burlaga
K. W. Ogilvie
J. W. Sari

Laboratory for Extraterrestrial Physics
NASA-Goddard Space Flight Center
Greenbelt, Maryland 20771

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We consider that the letter of Belcher et al., (1970), hereafter to be referred to as BCDJS, seriously misrepresents our work. We shall summarize some of our previous results here, but would hope that the reader will take time to study our papers in detail.

In the letter by BCDJS, they identify three areas of disagreement. The first, "have waves been successfully identified in interplanetary space?", is not really a matter of disagreement. Sinusoidal oscillations in $\vec{B}$ have been identified by Burlaga (1968) on the scale of 1 hour and by Unti and Neugebauer (1968) on a larger scale. The latter reported convincing correlations for the existence of Alfvén mode perturbations. Similar evidence was reported subsequently by Belcher, Davis and Smith (1969).

The second and third issues, the relative importance of waves and discontinuities and the extent to which discontinuities have been properly identified as being predominantly non-propagating structures, are matters of controversy. This "controversy" stems in part from a confusion on the vital question of time scales. Without a careful definition of a discontinuity, BCDJS have used results relevant to mesoscale studies to draw conclusions about microscale phenomena. We believe this to be a serious error on their part.

We strongly emphasize the importance of distinguishing microscale phenomena, $\approx$.01 AU = (1 hour), from larger scale phenomena. This point is clearly made in the papers of Burlaga and Ness (1968), Burlaga (1969) Burlaga and Ogilvie (1970), and Ness (1968, 1969). The definition of microscale referred to by BCDJS was introduced by us in an attempt to organize a description of the various structural features observed in the interplanetary medium. We further emphasize that there is

a difference between waves and discontinuities; and this difference can be seen quite readily if they are viewed on the microscale. On the larger scale, however, discontinuities are not clearly resolved and might be confused with wave like phenomena, which may well represent the presence of waves. It should be noted that only one of the graphs in the paper by Belcher and Davis (1970) is a microscale plot and the data itself with associated density variations, clearly indicates the possibility of misidentification of the type of discontinuity unless a careful analysis is conducted. Published results concerning waves by BCDJS are based on mesoscale plots and on statistical studies based on averages over time scales of 5 minutes to 3 hours to 1 day. On the other hand, we have studied microscale phenomena in considerably more detail as reported in several publications. Our studies are based on averages of 30 seconds or less, orders of magnitude better than the resolution used by BCDJS in their various publications discussing identification of waves.

Our initial studies of discontinuities were made without the benefit of plasma data. We introduced a clear working definition of a discontinuity, calling the general class "directional discontinuities" based upon the experimentally observed variation in direction of $\vec{B}$ across such a feature. We studied the statistical properties of these discontinuities and their relationship to the derived statistics of the power spectrum of magnetic fluctuations in interplanetary space.

The statistical properties of such directional discontinuities (Burlaga and Ness, 1968; Burlaga, 1969) are quite similar to those of

the discontinuities (defined somewhat differently) which were studied independently by Siscoe et al., (1968). Thus it appears reasonable to conclude that our "directional discontinuities" were essentially the same kind of structures studied by Siscoe et al. This is quite significant, for Siscoe et al. concluded from an analysis of the current sheets that the discontinuities were tangential. They also showed that the thickness distribution of these current sheets was strongly peaked at very small values, opposite to that which one would expect if the discontinuities were simply "abrupt" waves as suggested by BCDJS. Of course these are necessary but not sufficient conditions for tangential discontinuities. More recently, however, Smith et al., (1970) have used the same technique as Siscoe et al. (1968) to conclude that most "discontinuities" are rotational (i.e. "abrupt waves") in their interpretation.

Our early work did not conclude that all directional discontinuities were tangential. In fact it was explicity stated (Burlaga, 1968, 1969) that a large class of these discontinuities (called TO) could conceivably be made up of both tangential and rotational discontinuities. The available data at that time was not sufficiently complete to distinguish between these two classes. Indeed, it was with this possibility in mind that we called the discontinuities "directional" rather than "tangential". Earlier results of McCracken and Ness (1966) based on cosmic ray observations also supported the hypothesis that the discontinuities are mostly tangential. In the review papers by Ness (1968, 1969) the various possibilities for both discontinuities and waves were discussed and the problems associated with correct identification of waves, and tangential or rotational discontinuities clearly identified.

In the work of Sari and Ness (1969), it was shown directly that during several days in December 1966, the power spectral levels computed using standard techniques could be accounted for mainly on the basis of the observed discontinuities. A scaling error by a factor of 60 in the numerical code employed resulted in the discrepancy noted by BCDJS. However, since the same code was used for computing the spectra from either the theoretical ensemble of discontinuities or the actual data, the conclusions are unaltered.

This work by Sari and Ness was new in that it demonstrated for the first time that discontinuities can dominate in the contribution to power spectra as well as noting that what was really being measured was <u>wave number spectra</u> since the convective velocity is almost an order of magnitude higher than the propagation velocities of MHD waves. It differed significantly from the conclusions by Coleman (1966, 1967, 1968) that the observed power spectral level is due only to waves. Its validity is implicitly acknowledged in the last paragrah of BCDJS. Coleman's work is based on the linearized MHD equations of Thompson (1962) and does not include any discontinuties.

In a continuation of this work Sari and Ness (1969) showed that at quiet times the spectral levels are dominated by directional discontinuities while at other times, during disturbed conditions, the fluctuations between the discontinuities dominate the spectral shape and levels. This subsequent result has not been considered by BCDJS.

As plasma data became available, we showed that some discontinuities do satisfy those conditions necessary for identification of hydromagnetic

tangential discontinuities. Particularly significant were the multi-spacecraft observations (Burlaga and Ness, 1969) which showed that the orientation of some directional discontinuities in fact corresponded to that associated with tangential discontinuities. A more recent study (Burlaga, 1970) shows clearly that most of the discontinuities identified as directional discontinuities in our earlier work do not satisfy the conditions for Alfvén waves or (rotational discontinuities). Thus, during that period, discontinuities occurring at an average rate of 1 per hour were not Alfvén shocks or "abrupt Alfvén waves".

We have not published any evidence against the existence of waves. We have showed that intrinsic microscale fluctuations tend to occur when β is high due mainly to a high temperature (Burlaga et al., 1969). In another report, Belcher and Davis (1970) show that field fluctuations which they observed are very poorly correlated with $\beta_p = 8\pi nkT_p/B^2$. This conflicting result, based upon work utilizing 3 hour averages of plasma and field data, points up the importance of scale in such studies. The work of Burlaga et al. (1969) also showed that microscale fluctuations tend to be strongly associated with high β and that disturbed conditions occur very rarely when β is small. This latter work utilized 20.45 second averages of magnetic field data and clearly concerns a different phenomenon than that being studied by BCDJS in their publications.

We have also shown that the microscale fluctuations tend to be enhanced at positive bulk speed gradients (Burlaga et al., 1970). Contrary to suggestions by Jokippi and Davis (1969), they do not propagate away from these regions.

It is thus extremely important not to confuse microscale fluctuations with those seen on a larger scale. The results of BCDJS concern fluctuations generally on a rather larger scale, approximately 0.25 AU. Their "preliminary analysis" may be regarded as a confirmation of Coleman's conclusion that Alfvén or magnetoacoustic mode perturbations appear to be frequently present. Correlations between $\vec{V}$ and $\vec{B}$ on that scale do exist, as shown by Coleman, and they are seen in our unpublished Pioneer 6 and Explorer 34 data when plotted on the mesoscale. However, we have published no conclusions concerning these experimental results.

The work of BCDJS has shown that at times there are fluctuations in the interplanetary medium on the scale of 3 hours or longer which satisfy necessary conditions for outwardly propagating Alfvén waves. (Note that one of the necessary conditions, $\delta |B| = 0$, was used as an assumption to obtain the effective zero levels of the magnetometer). This is not sufficient to uniquely identify the perturbations as Alfvén waves, and the use of a classical linearized MHD theory to explain the observed variations may not be valid since the magnetic field perturbations observed are approximately equal to the ambient field intensity. Moreover, it is clear from their own data plots that another necessary condition for the existence of an Alfvén mode disturbance, i.e., zero density perturbation, is not always satisfied. In conclusion, we believe that BCDJS do not further the study of the interplanetary medium in their own work by denying the presence of those phenomena which can only be studied on another scale of length and time.

REFERENCES

Belcher, J. W., P. J. Coleman, Jr., L. Davis, Jr., D. E. Jones and E. J. Smith, Waves and Discontinuities in the Solar Wind, preprint submitted to J. Geophys. Res., 1970.

Belcher, J. W. and L. Davis, Jr., "Large amplitude Alfvén waves in the interplanetary medium: II; J. Geophys. Res., 1970, in press.

Belcher, J. W., L. Davis, Jr., and E. J. Smith, "Large amplitude Alfvén waves in the interplanetary medium: Mariner 5", J. Geophys. Res., 74, 2302, 1969.

Burlaga, L. F., "Micro-scale structures in the interplanetary medium", Solar Physics, 4, 67, 1968.

Burlaga, L. F., "Directional discontinuities in the interplanetary magnetic field", Solar Physics, 7, 54, 1969.

Burlaga, L. F., and N. F. Ness, "Macro- and micro-structure of the interplanetary magnetic field", Can. J. Phys., 46, S962, 1968.

Burlaga, L. F. and N. F. Ness, Tangential Discontinuities in the solar wind, Solar Phy. 9, 467, 1969.

Burlaga, L. F., "On the nature and origin of Directional Discontinuities" NASA-GSFC preprint X-692-70-462, submitted to J. Geophys. Res., 1970.

Burlaga, L. F., K. W. Ogilvie and D. H. Fairfield, Microscale fluctuations in the interplanetary magnetic field, Astrophys. J., 155, L171, 1969.

Burlaga, L. F., and K. W. Ogilvie, "Magnetic and thermal pressures in the solar wind", NASA-GSFC preprint X-69-70-268. To appear in Solar Physics, in press, 1970.

Burlaga, L. F., K. W. Ogilvie, D. H. Fairfield, M. D. Montgomery, and S. J. Bame, "Energy transfer at Colliding Streams in the solar wind", NASA-GSFC preprint X-692-70-270. To be published in Astrophys. J. in press, 1970.

Coleman, P. J., Jr., Hydromagnetic Waves in the Interplanetary Plasma, Phys. Rev. letters 17, 207, 1966.

Coleman, P. J., Jr., "Wave-like phenomena in the interplanetary plasma: Mariner 2", Planetary Space Sci., 15, 953, 1967.

Coleman, P. J., Jr., "Turbulence, viscosity, and dissipation in the solar wind plasma", Astrophys. J., 153, 371, 1968.

Davis, L., Jr. and E. J. Smith, "The inflight determination of spacecraft field zeros", Trans. Am. Geophys. Union, 49, 257, 1968.

Jokipii, J. R. and Leverett Davis, Jr., Long wavelength turbulence and the heating of the solar wind, Astrophys. J., 156, 1101, 1969.

McCracken, K. W. and N. F. Ness, The collimation of cosmic rays by the interplanetary magnetic field, J. Geophys. Res., 71, 3315, 1966.

Ness, N. F., Observed properties of the interplanetary plasma, Ann. Revs. Astron. and Astrophys., 6, 79-114, 1968.

Ness, N. F., "The magnetic structure of interplanetary space", Proceedings of the 13th International Conference on Cosmic Rays, Budapest, Hungary, 1969 .

Sari, J. W. and N. F. Ness, "Power spectra of the interplanetary magnetic field", Solar Physics, 8, 155, 1969.

Sari, J. W. and N. F. Ness, Power Spectral Studies of the Interplanetary Magnetic Field, NASA-GSFC preprint X-616-69-358. To be published in Proceedings of the 13th International Conference on Cosmic Rays, Budapest, Hungary, 1969, in press.

Siscoe, G. L., L. Davis, Jr., P. J. Coleman, Jr., E. J. Smith and D. E. Jones, "Power spectra and discontinuities of the interplanetary magnetic field: Mariner 4", J. Geophys. Res., 73, 61, 1968.

Smith, E. J., J. Belcher, L. Davis, Jr., and P. J. Coleman, Jr., The identification of interplanetary field fluctuations as traveling waves, Trans. AGU 51, 412, 1970.

Thompson, W. B., An Introduction to Plasma Physics, Chap. 5. Pergamon Press, N. Y., 1962.

Unti, T. W., J., and M. Neugebauer, Alfvén waves in the solar wind, Phys. Fluids, 11, 563, 1968.